

REPORT OF THE SURVEY OF THE COLORADO OF THE
WEST.

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

TRANSMITTING

A report of the survey of the Colorado of the West, and its tributaries.

JANUARY 31, 1873.—Referred to the Committee on Appropriations and ordered to be printed.

LETTER FROM PROFESSOR HENRY.

SMITHSONIAN INSTITUTION,
Washington, D. C., January 25, 1873.

SIR: I have the honor to present a second preliminary report of a survey made in accordance with an act of Congress at its last session "for continuing the survey of the Colorado of the West, and its tributaries, by Professor J. W. Powell, under the direction of the Smithsonian Institution."

The region embraced in this survey is one of the most interesting, in a geological point of view, in this or in any other country. The Colorado of the West, with its tributaries, as I have stated in my letter of March 29, 1872, traverses chasms in some places over a mile below the general surface of the country, presenting in many places at one view sections of the greater number of all the known geological formations in America.

According to the report herewith submitted, the survey of the past year has developed a most remarkable series of faults and folds of the earth's strata, which will be of the highest interest to the geologist.

The importance of the exploration, however, is not confined to the advance of science, but is also associated with practical results of value, such as the discovery of coal, salt, the metals, and other resources of the country.

Professor Powell has also studied the ethnology of the regions explored, and the specimens which he has collected in regard to this subject, as well as those relative to mineralogy and geology, now on separate exhibition at the Institution, evince highly commendable industry. The professor has also furnished a minute account of his method of carrying on the topographical survey, from a critical examination of which I am convinced the work has been done as well as the amount of

appropriation would permit and the wants of the country at present require. The work is much more than a mere exploration, since it is founded on a system of triangulation on a base line of nine miles accurately measured.

In view of the results obtained at a comparatively moderate expense, I would respectfully commend the application of Professor Powell for a renewed appropriation for continuing his explorations and surveys.

I have the honor to be, your obedient servant,

JOSEPH HENRY,

Secretary Smithsonian Institution.

Hon. J. G. BLAINE,

Speaker of the House of Representatives.

REPORT OF PROGRESS MADE IN THE SURVEY OF THE COLORADO RIVER
OF THE WEST, AND ITS TRIBUTARIES, BY J. W. POWELL.

WASHINGTON, D. C., *January 17, 1873.*

SIR: I have the honor to submit herewith a report of the progress made in the exploration of the Colorado River of the West and its tributaries, by the party under my charge, for the time intervening between the 1st of February, 1872, and the 1st of January, 1873.

This report is made in obedience to your instructions, given for the purpose of executing the will of Congress, expressed in the following extracts from the laws: From "An act making appropriations for sundry civil expenses of the Government for the year ending June 30, 1872, and for other purposes," approved March 30, 1871, viz: * * * * *
"For continuing the completion of the survey of the Colorado of the West, and its tributaries, by Professor Powell, under the direction of the Smithsonian Institution, twelve thousand dollars." * * * * *
And also from "An act making appropriations for sundry civil expenses of the Government for the fiscal year ending June thirtieth, eighteen hundred and seventy-three, and for other purposes," approved June 10, 1872: * * * * * "For completing the survey of the Colorado of the West and its tributaries, by Professor J. W. Powell, under the direction of the Smithsonian Institution, twenty thousand dollars." * * * * *

BASE-LINE AND PRIMARY TRIANGULATION.

In my last report, bearing date of March 25, 1872, I stated that a location for a line, to form the base for a system of triangulation, had been selected in the valley of the Kanab. During my absence from the field this line was measured under the direction of Professor Thompson. The method adopted for its measurement was that of wooden rods leveled on trestles. More specific details of its measurement will be given in my final report. The distance between the extremities of the line, which were points available for geodetic observations, was found to be about 49,000 feet. When this measurement was completed the entire field party was employed in selecting geodetic points, erecting monuments at such points, and making the necessary observations for the triangles, until the system was extended from the mountains on the west side of the valley of Virgen, to the Colorado on the east; and from the Grand Cañon on the south, to the head of the Sevier and the Dirty Devil

Rivers on the north. The observations for the angles were made with an eight-inch theodolite.

SECONDARY TRIANGULATION AND TOPOGRAPHICAL SKETCHING.

This triangulation completed, the party was employed in establishing secondary points, or flag-stations, by the use of the gradientor, and sketching the topography, and locating salient points from the flag-stations; and this work was continued until all that region embraced in the triangulation was completed.

EXPEDITION TO THE MOUTH OF THE DIRTY DEVIL RIVER.

In my last report it was stated that one of the boats was *cached* at the mouth of the Dirty Devil River for future use. Early in June, Professor Thompson reached the mouth of this stream, and there divided his party, sending a portion to proceed down the river in the boat to complete the work left unfinished the year before. The boat party made a successful trip to the mouth of the Paria, accomplishing all that was designed. Mr. F. S. Dellenbaugh, one of the assistant topographers, had charge of this work.

Professor Thompson, with the remaining portion of the party, proceeded to a group of eruptive mountains lying in a southwesterly direction, and, having completed the survey of these, passed over a series of cliffs, which were located, *pari passu*, to the mouth of the Paria, where he joined the boat party which had been waiting for him nearly a week. The mouth of the Paria had previously been designated as the point at which I should join the party, and proceed to survey Marble and Grand Cañons.

Professor Thompson proceeded at once to repair and repaint the boats and put everything in readiness to start. The material necessary had previously been sent from Kanab in wagons, by a route discovered in the former exploration.

RETURN TO THE FIELD.

On the 5th of July last I left Washington on my way to the field. On my arrival at Salt Lake City I purchased a team, and, taking two assistants with me, proceeded to Kanab, where I met Professor Thompson. From there I sent rations to the mouth of the Paria, deemed sufficient to last the party from that point to the mouth of the Kanab.

EXPEDITION TO THE KAIBAB PLATEAU.

With Professors Thompson and De Mott, one general assistant and a small party of Indians, I passed to the south end of the Kaibab plateau and established a series of stations, to be used in locating the meandering line of the river. This accomplished, we continued along the eastern brink of the Kaibab plateau, crossed House Rock Valley to the foot of House Rock plateau, and from thence to the mouth of the Paria, where I joined the party on the 13th of August.

SURVEY OF MARBLE AND GRAND CAÑONS.

Here I found everything in readiness for the trip through the lower cañons. It had previously been determined to take but two boats on this expedition, and the boat having received the greatest injury in the

former work was abandoned. A land party was sent back to Kanab with instructions to take rations from thence to the mouth of Kanab Cañon, where it enters Grand Cañon, and to arrive at that point one week earlier than the time at which the boat party was expected to be there.

The Paria River enters the Colorado along the strike of a monoclinical fold. Two days were expended in making a geological section of this fold, and connecting it with the grand section along the Colorado. We then proceeded through Marble Cañon to the junction of the Little Colorado. The geological work was carried on as in the cañons above; the topographical work also, with the exception that, from time to time, points along the river were located from stations previously established along the brink of the cañon.

At the junction of the Little Colorado we established an astronomical station, measured the altitude of the walls, and made a series of barometrical observations contemporaneous with another series made at Kanab. Then we entered the Grand Cañon of the Colorado, which extends from the mouth of the Little Colorado to the mouth of the Grand Wash, a distance of more than two hundred miles. The height of the walls, or the depth of the cañon below the general surface of the country varies from 4,000 to 6,000 feet. Through this gorge the waters of the Colorado flow. The waters of the Grand and Green, with all their tributaries, unite far above; then the Dirty Devil, San Juan, Paria, Little Colorado, and many smaller streams pour in their waters. Below the Grand Cañon, the Virgen and the Gila are the only considerable rivers that flow into the Colorado. The waste of the stream as it runs through the sand plains below, and its loss by evaporation, are probably greater than its gain through these two last-mentioned rivers; so that the Colorado has a greater volume of water through the Grand Cañon than in any other part of its course. All this water rolls through a channel varying from 50 to 300 feet in width, and plunging down from five to 200 feet to the mile. The banks of the river are cliffs of solid rock, often vertical for hundreds or thousands of feet; but in places these cliffs, or walls of the cañon, are broken down in steep slopes, and in other places they are terraced on a grand scale, the glacis often being from a half mile to a mile in width, and the step to a higher terrace several hundred feet. There is no proper flood-plain along the river through this cañon, but usually rocks have fallen down from the walls on one or both sides, so as to form a talus, varying from 25 to 300 feet in height. But in other places there is no talus, the river filling the channel from wall to wall. Numerous streams come down from the high plateaus on either side, each having its own winding cañon, and these have tributary cañons, making the topography adjacent to the river exceedingly intricate.

Having thus given a general sketch of the region to be surveyed, I will describe the way in which it was accomplished. We started from the mouth of the Little Colorado on the 24th day of August, running but a few miles each day, taking the meandering course of the river, as explained in the report of last year, but fixing our position from time to time by observations on the stations established on the summit of the walls, and sketching the topography of the lower part of the cañon. On coming to a lateral cañon, a small party would be sent up to trace its course as far as practicable. From time to time parties would climb on to the terraces or brink of the wall on the south side of the cañon, and establish the position of conspicuous points by observations on the stations before mentioned.

The barometrical observations were continued until all the instruments were unfit for service. The tossing of the boats by the waves, in running rapids, soon caused our barometers to leak, and we were compelled almost daily to refill a tube, until at last our supply of mercury was exhausted, and even the mercury of the artificial horizon was used, and we could no longer continue the series, which was broken off about midway in the cañon. All of these observations were made simultaneously with a series at Kanab. The altitude of this latter place had previously been determined.

We arrived at the mouth of the Kanab on the 7th day of September, and there met the land party as previously arranged. In coming down the cañon to this point, we found the water much higher than when the original exploration was made three years before. There was a good stage of water when we started from the mouth of the Paria, due to the melting of the great snows of last winter, but while on the way many heavy rains fell, and the river was kept constantly rising. The rise on the night of the 30th of August was 15 feet. At many points this great increase in the volume of water was an advantage, covering the rocks with which the river is beset, and saving many portages; but in very narrow portions of the cañon the increase of water gave us more difficulty, and made the navigation extremely perilous. In such places the difference between low and high water mark is often as much as 100 feet. For this reason we determined not to run the lower portion of the cañon, or that between the mouth of the Kanab and the Grand Wash. In the original exploration the topographical notes and sketches of the upper part of this cañon were lost, (it will be remembered that the men who were carrying out part of the records of the expedition were killed by Indians,) but the map of that portion of the cañon below was saved. I desired to proceed through the cañon for the purpose of making more thorough geological examinations of some parts, but it was not deemed wise to expose the party to so much danger for that single purpose, and so it was determined to abandon the boats and leave the river.

PROFESSOR THOMPSON COMPLETES THE TOPOGRAPHICAL WORK OF THE GRAND CAÑON.

The entire party proceeded from thence to Kanab. Here the party was again divided. Professor Thompson, taking three assistants, and a small party of Indians, crossed the Kaibab plateau to a point on the brink of the cañon opposite the mouth of the Little Colorado, and ran a system of triangles across the river from point to point, sketching the topography of the upper portion of the cañon and the upper ends of the lateral cañons, and carried this work down to the Grand Wash, thus completing the topography of this monstrous gorge, with all its accessory canons.

MR. HILLER WITH SMALL PARTY GOES TO THE "PROVINCE OF TUSAYAN."

Mr. Hiller was sent with a small party across the Colorado to the seven ancient towns, called by the Spaniards, "The Province of Tusayan," for the purpose of making a collection of their works of art, and a series of photographs. He was successful in carrying out the first object, but, through an accident to the photographic apparatus, only a few negatives were procured.

MR. JONES PROCEEDS TO TRACE THE CANONS OF THE UPPER VIRGEN.

Mr. Jones, one of the topographers, was sent with one assistant to trace the cañons of the Upper Virgen, which work he accomplished satisfactorily.

EXAMINATION OF A SERIES OF FAULTS.

With a small party I proceeded to examine the northern extension of a series of great faults, of which mention will be made hereafter.

SURVEY OF THE UINKARET MOUNTAINS.

On the 28th day of October, by previous arrangement, Professor Thompson's, Mr. Jones's, and my own party met again at Kanab, and on the day following, taking three Indians with us, started for a group of volcanic mountains on the north side of the Grand Cañon, and west side of the Kanab, called by the Indians "Uinkarets," which name we have adopted. The group is composed of three great table-shaped masses of basalt, and about sixty cinder cones. On the highest mountain, Mount Trumbull, one of the original geodetic points is situated. We established two others, which gave us two fixed lines, Mount Trumbull being one terminus to each. From these two bases the whole group was triangulated. Each cone was climbed, its position established, and observations taken to determine its altitude above the sea, and also its altitude above the basaltic table upon which it stands. While the topographical party was at work at this the geological party was engaged in examining the structure of the tables and cones. It proved to be a very instructive study, and a large body of facts was collected. Completing this work we returned to Kanab, where we arrived on the last day of November, having finished work for the season.

RETURN TO WASHINGTON.

Here we found Mr. Hiller, who had returned from the "Province of Tusayan." One day was devoted to packing fossils and other collections, and on the next I started with such members of the party as were to return to their homes, taking two teams.

These men were Mr. S. V. Jones, Clement Powell, and Andrew Hatton. We arrived at Salt Lake City on the 15th of December, at Chicago on the 20th, where the three men were discharged. My own arrival at Washington was on the 5th of January.

PARTY REMAINING IN THE FIELD.

Professor Thompson, with the remaining members of the party, was left in the field to prosecute the work during the winter. It is expected that he will be employed about two months in the office preparing a diagram of the triangles and a map of all the work which has been finished. Mr. Dellenbaugh, the chief draughtsman, will remain with him until this work is finished, when he will bring with him to Washington the diagrams and maps, which will be submitted to you for examination.

COLLECTIONS.

During the past year the following collections have been made: The upper portions of the walls of the Grand Cañon are composed of rocks

of the carboniferous age, and from these a fair collection of fossils has been made. Farther to the north, passing over the Triassic, Jurassic rocks are found. From these a small collection of fossils was procured. Still farther to the north cretaceous formations crop out, from which we obtained an interesting series of fossils. Continuing north we reach the plateaus in which are found the sources of the Virgen, Kanab, Paria, Dirty Devil, and Sevier Rivers. The sedimentary rocks, stretching across the summits of these plateaus, are of Tertiary age, and from them we obtained some fossils.

The walls of the lower portion of the cañon, for the greater part of its course, are composed of granites and metamorphic crystalline schists, with dikes of eruptive rocks. An extensive collection of these various rocks was made on our trip through the cañon. Large collections of the volcanic rocks of which the Uinkaret Mountains are composed was made. There are many other districts, composed of volcanic rocks, in the Territory embraced in the survey, from which suits of specimens, representing the different varieties, were collected. A collection of about five hundred species of plants has been made.

It was mentioned above that Mr. Hiller was sent to the "Province of Tusayan." He brought back with him a large quantity of stone implements, pottery, basket-ware, clothing, bows and arrows, and many other articles.

With all land parties Indian assistants have been employed. My object in doing so was threefold, viz: firstly, to conciliate the Indians; secondly, their services were of great value; and, thirdly, I desired to study their language, habits, and customs, and the state of arts among them. This has given me a good opportunity for making a collection of all articles of their manufacture, embracing stone implements, basket-ware, clothing, utensils for domestic use, instruments for hunting, trapping, and fishing, for dressing skins, musical instruments, ornaments of feathers, bone, claws, teeth, and various other things; instruments for kindling fire, and many miscellaneous articles. I also procured many varieties of these works in an unfinished state to show the different stages of their manufacture. These tribes live largely on fruits and seeds. Collections were made of such fruits as they were prepared by the Indians for preservation. A great variety of the seeds was obtained, amounting in all to twelve or fifteen bushels. And I also had a part of the seeds roasted and ground by the Indians, so as to exhibit the character of the meal which they use. All of these collections, except the plants, of which mention will be made hereafter, were transported to Salt Lake City in wagons and shipped to the Smithsonian Institution by rail, and they have arrived here in safety. Altogether the collection is large, filling twenty cases. The collection of plants was made by Mrs. Thompson, the wife of Professor Thompson, who has remained at Kanab, where we have had a depot of supplies from the commencement of the work. With the assistance of Professor Gray, of Cambridge, she is studying the plants this winter, and will send them to the Smithsonian Institution early in the spring. She has also had charge of the barometrical record, which has been kept up at that point many months.

ETHNOLOGICAL STUDIES.

It has been my habit to have two or three intelligent Indians ride with me wherever I have gone. This has afforded a rare opportunity for talking with them on the journey and in camp, and I have made it available in the study of their language, having collected more than two thou-

sand words and obtained some knowledge of the grammar of their language, such as the declension of the pronoun and noun, conjugation of the verb, modification of adjectives, their use of numerals, and many idiomatic expressions. I have also discovered among them a very elaborate system of mythology, which is their explanation of the origin of things, their authority for habits and customs, and their common or unwritten law. I have also collected a number, perhaps three or four score, of their simple songs. Their marriage and burial customs have been noted, and many other interesting facts observed. Of the people who inhabited this region of country antecedent to the present races, I have collected many additional facts this year, among which are the locations of seventeen additional communal houses, making in all more than a hundred thus far discovered. I have also added to the collection of picture—writings, or etchings on the rocks. These were copied by Mr. Dellenbaugh upon a scale of one-sixteenth, and I have the copies with me.

SUMMARY STATEMENT OF WORK PERFORMED.

In order that I may more fully explain the character and extent of the work that the party is performing in the field, permit me to make a brief statement of the general topographical and geological features, and the extent of the region embraced in the survey.

That portion of the river which has been explored is about one thousand miles in length. Commencing at the point where the Union Pacific Railroad crosses Green River, which is the upper continuation of the Colorado, the river flows in a direction a little west of south for a distance of something more than seven hundred miles, until the Little Colorado is reached. From that point its general trend is to the west for a distance of more than two hundred miles, where it turns again to the south. The river had been explored from its mouth to this point, and our survey extends no farther down. On the east and south of the river the survey runs back from the stream from ten to forty miles, being determined principally by important topographical features. But, on the north and west, all that region of country drained by the tributaries of the Colorado, from the Rio Virgen on the south to the Dirty Devil River on the north, has been included. The extent of this territory, in general terms, may be stated to be three hundred miles in length and one hundred and seventy-five miles in breadth. On the general map of the "Territory of the United States," prepared at the War Department, a copy of which I herewith transmit, the entire district of country is left as a blank, it having previous to this expedition been unexplored. The San Rafael, which appears on this map, is the stream next on the north of the Dirty Devil. The affluents of the San Rafael from the south have not been explored. When that is done all that blank can be filled with the proper topographical delineations. (I will mention here that the present appropriation will be sufficient to complete this work.) All this topographical work has for its basis the line previously mentioned as the measured base-line, and situated approximately as represented by the red line on the accompanying map. The latitudes of the extremities of the line have been determined by a series of observations with the sextant, for the altitude of the sun, certain planets, and stars; and also by a series of observations on convenient stars with a zenith telescope. The longitude of the line has been determined by telegraph connecting with a monument in Salt Lake City, the longitude of which point had previously been determined by officers of the Coast Survey.

The triangulation previously mentioned has determined the position of a series of geodetic points, and from these the locations of the general topographical features have been determined.

The principal tributaries of the Colorado from this country, commencing on the north, are the Dirty Devil, a stream of about the same size yet unnamed, Escalanti River, the Paria, Tapeat's River, the Kanab, and the Rio Virgen.

The geological agencies which have produced the strange and gigantic topographical features of this country are of three kinds, viz: 1st. Those of erosion; 2d. Those of disturbance of the level of the geological formations, causing folds and faults; and 3d. Those of eruptive agencies, by which sheets of lava have been poured over the surface, mountain masses thrown up, and cinder-cones formed. These three agencies have produced three distinct classes of topographical features: 1st. Erosion, under conditions which will not here be mentioned, has produced that labyrinth of deep gorges or cañons, that has made the country so nearly inaccessible that, before the present expedition, the region had been left entirely unexplored; 2d. The faulting and folding of the rocks have, together with erosion, produced long lines of cliffs of a magnitude that is believed to be elsewhere unknown. These cliffs are bold escarpments, often hundreds or even thousands of feet high, great geographical steps, scores or hundreds of miles in length, presenting steep faces of rock, often quite vertical. Having climbed such a step, you descend by a gentle, sometimes imperceptible, slope to the foot of the next. There are thus presented several series of terraces, the steps to each of them being well-defined escarpments of rock, but the lateral outline very irregular, as the cliffs project sharp salients on to the plain below, and deep recesses are cut into the steps above by the streams that find their way down. It will be understood, from what has previously been said, that the summits of these terraces are not level, but slope back from the brink of the cliff. The highest terrace is usually a forest-clad plateau, the ascent to which is made by a gigantic geographical stairway, as above described. The third class of agencies, in conjunction with erosion, has produced a number of black mesas, composed of sheets of cooled lava. On these mesas, and directly over the fissures through which the lava was ejected, naked, black cinder-cones, usually with well-defined craters, have been thrown up. These mesas and cinder-cones are all of basalt. The earlier eruptions were of trachyte, rhyolite, and other related rocks; and these formations are found in short mountain-ranges which stand athwart the grand valley, or are situated on the plateaus.

From a line some distance south of the Grand Cañon to a line somewhat north of the district under discussion, all the geological formations have a general dip to the north, so that a line extending from the most southern bend of the Grand Cañon north, onto the plateau in which the sources of the Dirty Devil River are found, would pass over the upturned edges of more than 25,000 feet of geological strata. Commencing below, in the bottom of the cañon, we have about 1,000 feet of granites and metamorphic crystalline schists. Abutting against this group of rocks, and non-conformable with it, are found 10,000 feet of sandstones and shales, with varying local dips. These rocks are of pre-carboniferous age. No fossils have been found in them, but the carboniferous rocks lie on their upturned edges, thus showing that there was a long period of erosion separating them. The carboniferous limestones, sandstones, and shales next succeeding are from 4,000 to 5,000 feet in thickness. Then we find about 2,500 feet of what I deem to be Triassic rocks.

Next we find from 1,000 to 1,200 feet of Jurassic rocks. Still surmounting these, we have from 1,800 to 2,000 feet of cretaceous beds, when we reach Tertiary rocks, at the south 3,000 or 4,000 feet in thickness, but farther to the north obtaining a thickness of nearly 7,000 feet.

Starting again at the Grand Cañon and passing north on the line above mentioned, in climbing the wall of the cañon to its summit, which is also the summit of the carboniferous rocks, we pass over two very distinct terraces. Continuing north thirty-five or forty miles we reach a low cliff, running in an easterly and westerly direction. The rocks exposed in the escarpment of this cliff are chiefly composed of chocolate-colored and variegated sandstones and marls, which are capped by a firmly-cemented conglomerate. The whole series is probably of lower Triassic age. In the conglomerate are found embedded many fragments, and sometimes huge tree-trunks of silicified wood. Like fragments are found scattered profusely over the surface of the conglomerate, collected from the degraded overlying rocks. The Indians call this wood *Shin-ar-ump*, or the rock of *Shin-au-av*; this *Shin-au-av* is the Hercules of Ute mythology, and the fossils are said to have been his arrows. The cliffs are called *Shin-ar-ump Mu-kwan-i-kunt*. It is proposed to call them *Shin-ar-ump* cliffs. Going on to the north ten or twelve miles we reach another line of cliffs from 1,000 to 1,800 feet high. The rocks seen in the escarpments are of buff and red sandstones, with variegated beds below. The series is supposed to be upper Triassic. The cliff is capped by a massive homogeneous sandstone. The lighter-colored rocks are usually stained bright-red on their surfaces. The Indian name for the secliffs is *Un-kar Mu-kwan-i-kunt*, or, "Vermillion Cliffs," which translation we have adopted. Climbing the Vermillion Cliffs and passing on to the north twenty-five or thirty miles a third line is found. Below, the rock is of white homogeneous sandstone; above, we have 200 feet of light-gray limestone, containing Jurassic fossils. For this line we have also adopted the English translation of the Indian name, Gray Cliffs. Still continuing to the north about thirty miles we pass over sandstones and shales of Cretaceous age, the cut edges of which to the east stand in two lines of cliffs, which we have not yet named. (Indian name not yet discovered.) We now reach the foot of another line of cliffs which form the southern boundaries of two great plateaus, the general surfaces of which are from 8,000 to 9,000 feet above the sea. These plateaus are separated by the valley of the Sevier; the one on the east we call *Powns-a-gunt*, meaning Beaver Plateau; the one on the west *Mar-ka-gunt*, which signifies the plateau of flowering bushes; the escarpments forming the southern limits we have named Pink Cliffs. All of these lines of cliffs are of very irregular outline, sometimes deviating from their general courses several miles. Sharp salients are set out onto the terraces below, deep re-entering angles are seen, and in many places the channels for intermittent streams have been cut through them, so that the terraces can be climbed by passing up a cañon. The *Shin-ar-ump* Cliffs are exceedingly irregular, often disappearing in slopes for miles. This line has been traced from near the head of the Santa Clara, a western tributary of the Virgen, across the Colorado to the "*Kut-sen Tu-weap*," a tributary of the Little Colorado, a distance of more than two hundred miles. The Vermillion Cliffs have been traced more than two hundred and fifty miles; the Gray Cliffs still farther. The unnamed cliffs in the Cretaceous rocks trend from the valley of the Kanab to the northeast until the Colorado River is reached, where they turn to the southeast, in which direction they extend to an unknown distance. The "Seven Ancient Cities" of the "Province of Tusayan"

are built on salients of these cliffs, and they are further interesting as being the repository of extensive beds of coal. The "Pink Cliffs" extend from the southwest corner of the Mar-ka-gunt Plateau to the southeast corner of the Powns-a-gunt, about fifty miles. All of these cliffs are approximately parallel, and are the result of like causes, similarly conditioned.

Transverse to these another series of cliffs is found, which mark the lines of a great system of faults. The most westerly of these faults discovered by the party is on the eastern side of the Grand Wash, extending across the river to the south. This has been but partially examined. It is yet uncertain whether there be two faults or one with two branches. The drop of the fault is to the west. On the eastern side of the fault the broken edges of the strata stand in a bold escarpment, forming what we have named the Grand Wash Cliffs—the western wall of this wash. Going farther east, another fault is discovered, approximately parallel to the first. The drop of the beds is also on the west. It extends from an unknown point south of the Colorado (it has been traced about thirty miles to the south without discovering its termination) to a point far north of Tokerville. (Its northern terminus has not been discovered.) The drop is from 1,300 to 2,800 feet. The broken edge of the rocks on the eastern side of the fault, which have not been displaced, forms a remarkably steep escarpment, in much of its course a sheer precipice, impossible to be scaled, even by men accustomed to mountain-climbing. Several small towns have been located along its foot, and the people have given to the cliff the name of "Hurricane Ledge;" but, in order to conform this name to my general nomenclature, I call it Hurricane Cliff; the fault, Hurricane Fault. It will be observed that the direction of these faults is, in a general way, at right angles to the grand strike of the formations. From the Colorado north to the Shin-ar-ump Cliffs the surface of the country between these two faults is the summit of the carboniferous formation, except that in some places floods of lava have been poured out upon the plain prior to the degradation of the lower beds of the Triassic. In such places the basalt, being of superior hardness and firmer texture, has furnished a protection from erosion, and mesas have been left. It has already been stated that the grand dip of the formations is to the north, but the disturbances causing these faults have produced a secondary dip to the east; so that the district of country under consideration has a general dip to the northeast composed of the two elements. Just along the line where the summit of the carboniferous formation disappears under the Shin-ar-ump Cliffs, a short local fold is seen, its axis running in an easterly and westerly direction, in line with the cliffs. It will thus be observed that the district of country here described forms a plateau, with a slope to the northeast, bounded on the north by the short local fold, on the south by a portion of the Grand Cañon, on the west by the cliffs of the Grand Wash, and on the east by a cañon of denudation running along the foot of the Hurricane Cliff into the Colorado. For this we have adopted the Indian name, Sheav-wits Plateau.

Going yet farther east about twenty-five miles another fault is observed. This has been seen to extend south of the cañon thirty miles; how much farther is unknown. It has been traced to the north through the Vermillion Cliffs, where the Short Creek Cañon marks its position. Where it crosses the Shin-ar-ump Cliffs, the displacement is seen to be about 120 feet. On the north side of the Grand Cañon it is marked by a cañon valley about thirty miles long, to which we have given the name of To-ro-weap. At the foot of the valley the drop was measured and

found to be 820 feet; the drop appears to be greater on the south side of the cañon. The fault we have named To-ro-weap, and the cliffs the same. The Uinkaret Mountains, composed of basaltic tables and cones, are situated between this and the Hurricane Fault, and north of the Grand Cañon, of the Shin-ar-ump Cliffs.

Again, to the east another fault is discovered; we are yet uncertain whether this fault extends to the south of the Grand Cañon; the first point where it has been seen is about ten miles north of the cañon, from which place it has been traced north past Pipe Spring to the foot of Long Valley. The western wall of Long Valley is the escarpment formed by the cut edges on the eastern side of the fault. From the head of Long Valley it has been traced to the head of the valley of the Sevier, then down the valley of the Sevier and up the valley of the Sanpete, altogether a distance of more than two hundred and fifty miles. The drop of the rocks on the western side of the fault varies from 100 to about 3,000 feet. We have called this the Fault of the Sevier. Along its course several lines of cliffs have been designated as follows: The line on the east side of the Sanpete Valley, Sanpete Cliffs. From the foot of the Sanpete Valley to a point about midway up the valley of the Sevier, ranges of eruptive mountains are seen to the east; the rocks constituting these have probably emerged from the fissure of this fault, and have, to some extent, obscured it. South of these eruptive ranges, the eastern wall of the valley of the Sevier is a well-marked line of cliffs; it forms the western boundary of the Powns-a-gunt Plateau. To this line we have given the name Sevier Cliffs. Another line is seen on the eastern side of Long Valley, Long Valley Cliffs. Another fault is seen at the cañon of the Kanab, which has been traced about thirty miles; the drop is from one to two hundred feet, and still on the west. Being inconsiderable, no marked line of cliffs has been formed. This we call the fault of the Kanab. Another fault, farther to the east, marks the western boundary of the Kaibab Plateau. This displacement, either as a fault or monoclinial fold, has been traced to the northern sources of the Dirty Devil River, and it probably extends more than one hundred miles farther. To this we have given the name of Western Kaibab Fault. The eastern edge of the Kaibab marks the line of another fault; this has been traced fifty miles south of the Grand Cañon, and probably extends still farther, as a continuation of the line would strike the San Francisco Mountains, a vast group of volcanic tables and cones, said to be nearly one thousand in number, and it is conjectured that the erupted matter issued from the fissures of this fault and its branches. This Eastern Kaibab Fault, like the Western, has been traced far to the north, and is believed to extend to Price River Valley. Here the drop changes, and it is found on the eastern side of the line. Still others have been found to the east, but none of them have been traced, having been seen only at points along their lines; hence no further mention of them will here be made. This great system of faults, unparalleled in geological annals, has been the subject of much careful study. Each fault has been traced by passing along its line through the whole extent of territory embraced in the survey. From time to time the drop has been measured, and a great variety of accompanying phenomena observed. Some of these facts are of much interest. In many places the faults are seen to branch; in others they are suddenly or gradually changed into monoclinial folds; in still others the drop marks but a portion of the displacement, the edge of the fallen rock having caught on the wall remaining *in situ*, has been turned up so that

below it appears as a fold, and above as a fault. Yet in other places the rocks are not separated by a well-defined fissure, nor are they folded, but irregular masses of broken and displaced rocks intervene. The facts connected with this system are very numerous and complicated, and in order to set them forth in a manner which shall be readily understood, it is proposed to construct a diagram of each fault, to represent the varying displacements. Accompanying this principal diagram will be others of transverse sections, to exhibit the features of the plain faults, the branched faults, the transition into monoclinical folds, the pure folds, and the broken displacements. The facts necessary to the construction of such diagrams have been collected as far as the system has been examined. All of the cliffs having an easterly and westerly trend are composed of a series of rocks, the lower members of which are exceedingly friable, invariably surmounted by rocks of a firmer texture that yield very slowly to atmospheric degradation. This has doubtless been one of the important conditions under which the escarpments were formed. It can also be shown that another of these conditions was, that the progress of the emergence of the folds from the sea was but little greater than the progress of erosion. There were also meteorological conditions modifying these, which will be discussed in my final report. The cliffs with a northerly and southerly trend have their origin in faults. The eruptive formations connected with these disturbances are of three general classes: First, the earlier eruptions, modified by subsequent erosion, have produced a number of mountain-ranges; second, later flows have produced sheets of basalt, that form the summits of low mesas and table-lands, or have partially filled and modified the valleys; third, the expiring energies of these agencies have left, standing in lines along the fissures, great numbers of cinder cones. Special maps of such volcanic districts have been prepared, it being necessary, in order to discuss the geology, to have more minute topographical delineations than the general map would present.

The mountain ranges mentioned in class 1 have not yet been carefully studied by the geologists. The basaltic formations have been somewhat carefully studied and it is not deemed best, in the present state of the geological knowledge of the western country, to make more minute examinations.

There is another group of facts of which mention should be made here. The cliffs and cañon-walls present everywhere such exposures of the rocks that the geological structure of the country may be easily studied and conclusions reached with a degree of certainty rarely attainable. Under these circumstances it has been possible to understand the causes which have been combined to determine the vast system of drainage. To set these facts in order it is proposed to classify the valleys, and to discuss them in geographical order, and then arrange them under their classes. Of simple valleys we have two orders: 1st, those which have a direction along the strike of the rocks, which are designated as *longitudinal* valleys; 2d, those which have a direction transverse to the strike of the rocks, which are designated as *transverse* valleys. Of the first order there are three varieties; *a*, valleys following anticlinal axes, called *anticlinal* valleys; *b*, valleys following synclinal axes, called *synclinal* valleys; *c*, valleys running in the direction of the strike between the axes of the fold, called *paraclinal* valleys. Of the second order there are three varieties; *a*, those crossing anticlinal axes, called *perclinal* Valleys; *b*, those running in a direction against the dip of folds, called *contractlinal* valleys; *c*, those running in a direction with the dip of folds, called *acclinal* valleys. Many of

the valleys are thus simple. Many others for parts of their courses would fall under one variety, and for other parts another variety; such are called *complex* valleys. Again, there are large valleys formed by the coalescing of simple and complex valleys, which are called *compound* valleys. Under the same classification the cañons will be discussed; in fact, no definite line of demarkation can be drawn between cañons and valleys. Intermediate depressions caused by erosion will be discussed under the head of cañon valleys. The topography being the result of geological causes, an explanation of the geological structure involves a description of the topographical features.

For the purpose of properly presenting the facts relating to the geological formations of the district under consideration, a number of sections have been prepared, briefly detailed as follows: First, the grand section, beginning a few miles north of the point where the Pacific Railroad crosses Green River, and extending down this stream and the Colorado, to the southern extremity of the survey at the mouth of the Grand Wash. This is about one thousand miles in length, unbroken for the entire extent, and exhibiting a vertical series of rocks, varying from a few feet to 6,000 feet in altitude, and a geological series of formations of nearly 30,000 feet in thickness. From time to time, vertical sections, giving the details of the stratification, have been made of the walls of the cañon, which will accompany the grand section. Second, another section has been made, beginning at the bottom of the Grand Cañon, and passing north along the line of the Hurricane Fault, to a point near to that where it crosses the Rio Virgen, and from thence continued to the summit of the Mar-ka-gunt plateau. Third, a section has been made along the Kanab from its mouth to its source. Fourth, a section has been made from the mouth of the Paria to its source. The last three combine the features of a running section and those of a vertical section; that is, they will represent the geological structure of the country along their lines and also give the details of stratification. Many other sections have been made to illustrate local peculiarities, and a large number which it will not be necessary to use in the final report, but the data collected for them will be of value in the general discussion. The limited appropriation made for this exploration has not permitted the employment of a special paleontologist, but the members of the geological corps have given all the time possible, consistent with their other duties, to the search for fossils, and collections have been made that will in most cases determine the age of the principal groups of rocks. These will be submitted to competent specialists for identification and such description as may be necessary.

It is believed that the mass of facts collected, as indicated in this brief summary, will not only be an interesting addition to the body of observations heretofore made by geologists in the Territories of the United States, but also that the deductions made therefrom will be a slight contribution to the general doctrines of the science.

The appropriation made for the fiscal year ending June 30, 1871, was \$12,000. With this, one thousand miles of a previously unknown river was explored, presenting physical obstacles greater than those of any other stream known to us in the world. In addition to the exploration of the river, the adjacent country, along the first five hundred miles, was surveyed, so as to include a territory of fifteen thousand square miles, and a geological reconnaissance of eighteen thousand square miles of additional territory.

The appropriation made for the fiscal year ending June 30, 1872, was \$12,000; for the fiscal year ending June 30, 1873, \$20,000. With this

money, fifty-two thousand five hundred square miles of territory has been surveyed, geographically and geologically; the topographical work having a trigonometrical basis.

PLANS FOR THE CONTINUATION OF THE SURVEY, WITH ESTIMATES OF COST.

I beg leave to call your attention to the two following plans for continuing these explorations: It was shown in my last report that a general reconnaissance had been made of the territory lying between the Wasatch Mountains and Sanpete Valley on the west, and Green River on the east. This embraces the valley of the Uintah, the ranges of mountains and extensive plateaus lying to the south, the valley of the Price River, the Wasatch Plateau, the valley of the San Rafael, and the plateau and eruptive mountains in which this river has its sources.

There are some special geological reasons for continuing this work. The great faults, of which mention has been made, extend through this country, and it is desirable that these should be traced to their northern termini. The cooled matter of the eruptive mountains has issued through the northern extension of the same great system of fissures; so these mountains are related in geological origin to those heretofore studied. The geological series of stratified formations exhibited in the grand section along the river has its lower members exposed for study in the country to the south, already surveyed, and its upper members to the north in the district under consideration. It will thus be seen that the geological studies here presented will complement the examinations heretofore made, and each throw much light upon the other.

To complete this survey, with the accuracy and elaboration of the work performed the past year, would require two years' time for a party no larger than the one heretofore employed; and an appropriation, as made last year, for each of the two years, would be sufficient. This would complete the survey of all that district of country south of the belt surveyed by Clarence King, west and north of the surveys made by Lieutenant Wheeler, and east of the Green and Colorado rivers.

An experienced corps is now organized and in the field, a train and outfit owned by the Government, the instruments in order for use, and but little addition would be necessary.

Should it be deemed best to complete this work in one year, it will be necessary to more than double the annual appropriation, as an additional train and outfit would be required, and inexperienced men would have to be employed. In such case forty-five thousand dollars would be sufficient.

The second plan for continuing the work is as follows: To run a system of triangles from the valley of the Sevier to the junction of the Grand and Green, in order to fix with approximate accuracy the head of the Colorado, and, at the same time, by use of the geodetic points thus established, to complete the survey of the valley of the San Rafael and of the mountains and plateaus in which it has its sources, then complete the reconnaissance of the upper country, and trace the great system of faults to where they are lost in the mountains on the north.

This upper portion of the map would have for its basis the meandering lines of travel followed by the exploring parties, instead of a base-line with established geodetic points.

All this could be completed during the next year with an appropriation of twenty thousand dollars. Should it be deemed best to have the work cease at the present stage, I will submit estimates of the approp-

priation necessary for the preparation of the report and the engraving of the maps.

I beg permission to call your attention to some facts connected with the administration of the affairs of the expedition: No charges for railroad transportation have been made against the Government except between Chicago and Washington. Again, by employing a small party and continuing the work during the entire year, it has not been necessary to sell the train and its equipments in the fall, at great loss, and repurchase in the spring at high prices. By this plan a great saving has been made. Lastly, heretofore all the work has been accomplished for which estimates have been submitted.

Invoking your careful consideration of this report, with the accompanying plans and estimates,

I am, with great respect, your obedient servant,

J. W. POWELL.

JOSEPH HENRY,

Secretary of the Smithsonian Institution.

